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# THEORETICAL ANALYSIS OF LOAD CARRYING CAPACITY IN A SHORT SQUEEZE FILM BEARING OPERATING WITH NANOFLUIDS

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## ABSTRACT

Squeeze film is a phenomenon of two lubricated surfaces approaching each other with a normal velocity. In this paper, by considering the Modified Krieger-Dougherty viscosity model, the influence of nanoparticle lubricant on the load carrying capacity of squeeze film journal bearing is studied. The pressure distribution and load carrying capacity are theoretically evaluated using a modified Reynolds equation. The results show that the additions of nanoparticles increase the viscosity of the lubricant and in turn an increase in load carrying capacity of journal bearing.

***Keywords:*** *Squeeze film bearing, Nano-lubricant.*

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## I. INTRODUCTION

Hydrodynamic squeeze films play an important role in engineering practice. The application of squeeze film action is commonly seen in the initial phase of wet clutch engagement, automotive engines and the mechanics of synovial joints in human beings and animals. The squeeze film behavior arises from the phenomenon of two lubricated surfaces approaching each other with a normal velocity. Because of the viscous lubricant present between the two surfaces, it takes a certain time for these to come into contact. Since the viscous lubricant has a resistance to extrusion, a pressure is built up during that interval, and the lubricant film then supports the load.

The squeeze film in a non rotating porous journal bearing with a full film of lubricant was studied by J. Prakash and S.K.Vij [1], Ramanaiah [2] analyzed the squeeze film behavior between finite plates of various shapes lubricated with couple stress fluids. N.M. Bujurke & Jayaraman [3] predicted the characteristics in a squeezefilm **Theoretical**

**Analysis**

Fig.1 represents the physical configuration of a journal bearing. The journal of radius r approaches the bearing surface with velocity V. The film thickness $h$ is a function of $\theta$ i.e., $h = c - e\cos\theta$, where is the radial clearance and e is the eccentricity of the journal center.

configuration with reference to synovial joints. J.R. Lin [4,5,6] applied the couple stress fluid model to predict the pure squeeze film characteristics of a long partial bearing, short bearing and finite bearing. Owing to the development of modern machine equipments the increasing use of non-Newtonian fluids as lubricants is becoming of interest. Nanoparticles lubricants are stable suspension of fine solid particles with the base fluid such as SAE oils. Addition of nanoparticles increases the viscosity of the lubricant and reduces the friction and wear. Even though the influence of nanoparticles lubricant additives on boundary lubrication regime is welldocumented [7,8,9,10,11,12,13,14,15,16,17], there is a lack of published data regarding their influence on Squeeze film lubrication regime. Thus the present paper focuses on the theoretical analysis of load carrying capacity of a narrow squeeze film journal bearing operating with nanolubricant.

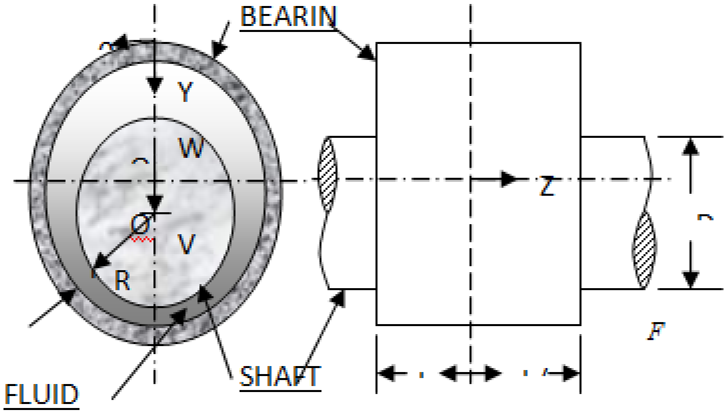

*Figure - 1: Squeeze Film Bearing*

R = Radius of the Shaft.
L = Length of the Bearing.
W = Load on the Shaft.
V = Approach Velocity of the Shaft.
Ob = Center of the Bearing
Oj = Center of the Shaft.
e = Eccentricity.
h = Fluid Film Thickness.

he Reynolds equation [23] for a journal bearing is

$$\frac{\partial}{\partial x}\left[h^3\frac{\partial p}{\partial x}\right]+\frac{\partial}{\partial z}\left[h^3\frac{\partial p}{\partial z}\right]=12\,\mu V \quad (1)$$

Where V is the shaft approach velocity, $h$ is the oil film thickness,

$\mu$ is the viscosity of the Nanolubricant and $p$ is the oil film pressure.

$V = \frac{dh}{dt}$ is the squeeze velocity The oil film thickness is$h = c(1 - \epsilon\, cos\theta)$

### 1.1. Boundary Conditions

The Reynolds Equation is an elliptical partial differential equation and therefore must be solved as boundary value problem.

P = 0 at $\theta = 90^0$ and $\theta = 270^0$
P = 0 at Z = + L/2, -L/2 (2)
Where θ = Circumferential angle, Z = Bearing axis parallel to the shaft axis.

### 1.2. Viscosity Models: Estimation of the Nanofluid viscosities:

There are certain theoretical formulas used to find the viscosities of Nanofluid.

(i) Einstein Model [18]

$$\mu_{nf} = \mu_{bf}\ (1 + 2.5\ \phi)$$

$$\bar{\mu} = \frac{\mu_{nf}}{\mu_{bf}} = (1 + 2.5\ \phi) \qquad (3)$$

Where $\phi$ is the volumetric concentration of Nanoparticals. Einstein’s formula can be used when $\phi \leq 0.02$.

(ii) Brickman [19] extended formula for moderate particle concentration as

$$\bar{\mu} = \frac{\mu_{nf}}{\mu_{bf}} = \frac{1}{(1-\phi)^{2.5}} \qquad (4)$$

(iii) Batchelor [20] derived a model considering the Brownian motion of particles of the fluid

$$\bar{\mu} = \frac{\mu_{nf}}{\mu_{bf}} = (1 + 2.5\,\phi + 6.5\,\phi^2) \qquad (5)$$

(iv) Kole and Dey [21]studied the viscosity variation with CuO nanoparticles in gear oil. The study identified a modified version of Krieger-Dougherty viscosity model to simulate viscosities which were in close agreement with experimental measurements.

$$\bar{\mu} = \frac{\mu_{nf}}{\mu_{bf}} = \left(1 - \frac{\phi}{\phi_m}\right)^{-[\eta]\phi_m} \qquad (6)$$

Where, $\phi_m$ is the maximum partical packing fraction, which is approximately 0.605. $[\eta]$ is the intrinsic viscosity whose typical value specified by Kole and Dey is 2.5.

The above equation was modified to consider the packing fraction within the nanopartical aggregate structure. The modified Krieger – Dougherty [22] equation is

$$\bar{\mu} = \frac{\mu_{nf}}{\mu_{bf}} = \left(1 - \frac{\phi_a}{\phi_m}\right)^{-[\eta]\phi_m} \quad (7)$$

$\emptyset_a = \emptyset\left(\frac{a_a}{a}\right)^{3-D}$ Value of D is 1.8 for and

$\phi_m = 0.605$ for Nanofluids.

$\frac{a_a}{a} = 7.77$ for $TiO_2$ based nano-lubricant.

## II. SHORT BEARING ANALYSIS

If the L/D ≤ 0.5, it is called short bearing or Narrow bearing. Neglecting the pressure variations in the x direction, the Reynolds Equation reduces to,

$$\frac{\partial}{\partial z}\left[h^3 \frac{\partial p}{\partial z}\right] = 12\,\mu_{nf}\, c\,\dot{\varepsilon}\cos\theta \quad (8)$$

$\mu_{nf}$ is the viscosity of the nanolubricant

### (i) The squeeze film pressure:

By Integrating twice the equation (8) with respect to z and applying boundary conditions from the equation (2) and solving equation (8),

$$p = \frac{6\,\mu_{nf}\,\dot{\varepsilon}\,Cos\theta\, L^2}{c^2(1+\in Cos\theta)^3}\left[\left(\frac{Z}{L}\right)^2 - \left(\frac{1}{4}\right)\right] \quad (9)$$

Let the dimensionless bearing pressure is

$$\bar{p} = \frac{pc^2}{6\,\mu_{bf}\,\dot{\varepsilon}\,R^2} \qquad \bar{\mu} = \frac{\mu_{nf}}{\mu_{bf}} \text{ where,}$$

$\bar{\mu}$ is the non-dimensional relative viscosity, $\mu_{nf}$ is the nanolubricant viscosity, which corresponds to $TiO_2$ based nanolubricant, and $\mu_{bf}$ is the viscosity of base lubricant.

Therefore,

$$\bar{p} = 4\left(\frac{L^2}{D^2}\right)\bar{\mu}\frac{\cos\theta}{(1+\in Cos\theta)^3}\left[\left(\frac{Z}{L}\right)^2 - \left(\frac{1}{4}\right)\right] \quad (10)$$

At the mid-plane of the bearing the dimensionless pressure is

$$\bar{p}_s = \lambda^2\,\bar{\mu}\frac{\cos\theta}{(1+\in Cos\theta)^3} \quad (11)$$

**(ii) Load Carrying Capacity:**
Squeeze load for the short bearing is

$$W_S = 2\int_{\pi/2}^{3\pi/2}\int_{0}^{L/2} P_s\, Cos\theta \cdot Rd\theta \cdot dZ \quad (12)$$

$$W_S = \frac{\mu_{nf}\,\dot{\varepsilon}\,RL^3}{c^2}\,\frac{\pi\left(1+2\in^2\right)}{\left(1-\in^2\right)^{\frac{5}{2}}} \quad (13)$$

Assume $\overline{W_S}$ = Dimensional less squeeze load

$$\overline{W_S} = \frac{W_S c^2}{\mu_{bf}\,\dot{\varepsilon}\,RL^3}$$

Dimensional less squeeze load

$$= \overline{W_S} = \frac{\pi\,\bar{\mu}\left(1+2\in^2\right)}{\left(1-\in^2\right)^{\frac{5}{2}}} \quad (14)$$

## III. RESULTS

In the present paper, for the analysis purpose the design parameters are chosen as follows: Nanoparticles concentration: 0.5 to 2.5 vol % ; eccentricity ratio */ε = 0.2 ~ 0.8. The results are shown in a graphical form. In Fig.2, the dimensionless squeeze film pressure is plotted against the bearing circumferential angle for different values of the volume fraction of the nanoparticles at the eccentricity ration of 0.6. It is observed that the volume fraction of the nanoparticles effects are predominant. For higher values of volume fraction of the nanoparticles, the hydrodynamic fluid film pressure is substantially higher. Fig.3. Displays the dimensionless load carrying capacity *W* Verses eccentricity ratio ε for different values of volume fraction of the nanoparticles. Since the volume fraction of the nanoparticles effects give a higher film pressure as compared to the Newtonian lubricant case, the integrated load carrying capacity is similarly affected. At the higher eccentricity ratios, the volume fraction of the nanoparticles is noticeable.

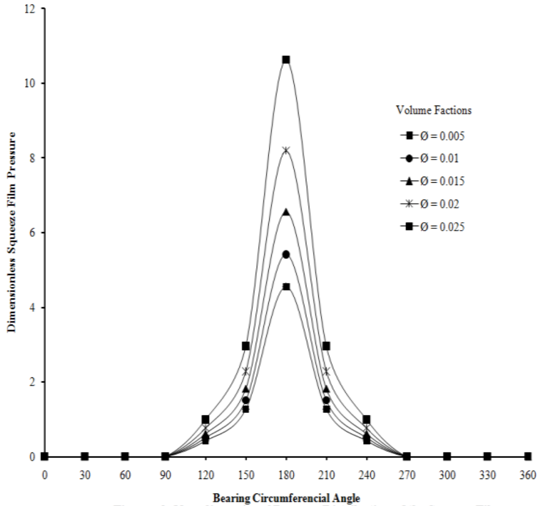

Figure - 2: Non-dimensional Pressure Distribution of the Squeeze Film

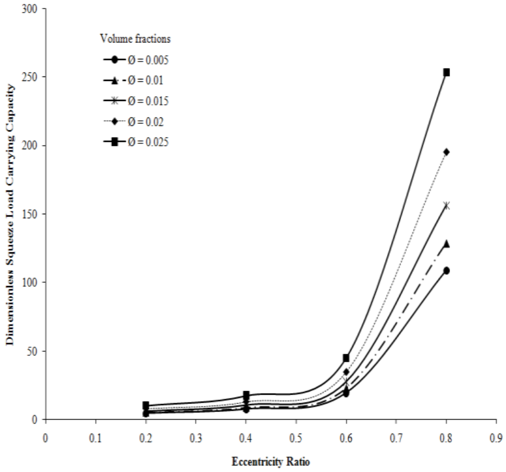

Figure -3: Eccentricity Ratio Vs Dimensionless Load Carrying Caopacity at various Volume Fractions

## IV.CONCLUSIONS

The study reveals that, the variation in lubricant shear viscosity due to the nanoparticles additives can be simulated using the modified Krieger-Dougherty viscosity model. Even at the low concentrations of 0.01 volume fractions, the load carrying capacity of the bearing is increased by 38.4%. Also as the volume of fraction increases the load carrying capacity also increases at any eccentricity ration.

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## Nomenclature

| | |
|---|---|
| a | Radii of primary nanoparticles (nm) |
| $a_a$ | Radii of aggregate nanoparticles (nm) |
| C | Radial clearance (m) |
| D | Fractal index |
| e | Eccentricity (m) |
| h | Film Thickness (m), |
| L | Length of the bearing (m) |
| P | Lubricant pressure (N/$m^2$) |
| R | Radius of the journal (m) |
| W | Load carrying capacity (N) |
| Ø | Nanoparticle volume fraction |
| $\mu_{bf}$ | Viscosity of base lubricant oil |
| $\mu_{nf}$ | Viscosity of nanolubricant. |
| Θ | Angular coordinate (rad) |